

TITLE OF THE INVENTION

PROTECTION RELAY

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the
5 benefit of priority from the prior Japanese Patent
Application No. 2001-057948, filed March 2, 2001, the
entire contents of which are incorporated herein by
reference.

BACKGROUND OF THE INVENTION

10 1. Field of the Invention

The present invention relates to a protection
relay in which an influence of distortion component of
fault current generated by a fault in a power system is
suppressed.

15 2. Description of the Related Art

Generally, a protection relay is used to monitor
a power system. A main technical subject of such a
protection relay is to reduce an influence of harmonics
in fault current and fault voltage generated in a fault
20 in a system contained in a signal inputted from the
system.

Particularly because charging capacity of a system
is increased in underground power transmission cable,
phase modifying capacitor and the like, the order of
25 generated harmonics tends to be lowered.

Thus, if it is intended to secure a desired
damping amount according to a conventional method for

damping the harmonic component with a digital filter, filter delay time needs to be prolonged, so that relay operation time is delayed.

For the reason, an approximation method, which is
5 not affected by harmonic theoretically even if such harmonics is contained has been employed in recent years.

An example of such approximation method will be
described with reference to FIG. 1. Power transmission
10 impedance constant up to a fault point F will be
considered with reference to FIG. 1. Voltage and
current of a protection relay installation point A
are assumed to be v and i when resistance is R and
inductance is L . If it is assumed that the voltage
15 at the faultal point F is zero, differential equation
of a power transmission line 2 can be expressed in
an expression (1).

$$V = R \cdot I + L \cdot (di/dt) \quad \cdots (1)$$

By calculating a differential item (di/dt) of the
20 expression (1) approximately, detection accuracy can be
improved even if harmonic is not removed with a filter.
An example of a concrete method for digital calculation
actually adapted is shown below.

$$v_m + v_{m-1} = R \cdot (i_m + i_{m-1}) + L \cdot (i_m - i_{m-1})$$
$$v_{m-1} + v_{m-2} = R \cdot (i_{m-1} + i_{m-2}) + L \cdot (i_{m-1} - i_{m-2}) \quad \cdots (2)$$

When a reactance value X ($= \omega_0 \cdot L$) is calculated
from the expression (2), the inductance is expressed in

expression (3).

$$\begin{aligned} L_m &= X_m / \omega_0 = \\ & \frac{(v_m + v_{m-1}) \cdot (i_{m-1} + i_{m-2}) - (v_{m-1} + v_{m-2}) \cdot (i_m + i_{m-1})}{(i_m - i_{m-1}) \cdot (i_{m-1} + i_{m-2}) - (i_{m-1} - i_{m-2}) \cdot (i_m + i_{m-1})} \\ & \dots (3) \end{aligned}$$

5

L_m/L (true value) is as expressed in the expression (4) under conditions of the expressions (5) and (6), so that frequency characteristic of X_m/X (true value) is as indicated with the dotted curve of FIG. 2.

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$$L_m/L(\text{true value}) = \tan(\omega_0 T/2) / \tan(\omega T/2) \quad \dots (4)$$

$$\text{Where, } i_m = I \sin(\omega t_m), v_m = V \sin(\omega t + \theta)$$

$$i_m - i_{m-1} = 2I \sin(\omega T/2) \cos(\omega t_m - \omega T/2) \quad \dots (5)$$

$$v_m + v_{m-1} = 2V \cos(\omega T/2) \sin(\omega t_m - \omega T/2 + \theta) \quad \dots (6)$$

15

Therefore, frequency characteristic of X_m/X (true value) is as indicated with the dotted curve of FIG. 2.

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In FIG. 2, its abscissa axis indicates frequency (order) and its ordinate axis indicates a reactance measurement value when basic frequency of system electrical quantity is 50 Hz. Further, in FIG. 2, its dotted curve indicates a case of sampling at 600 Hz and its solid line indicates a case of sampling at 4800 Hz.

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As indicated in FIG. 2, the value of L_m/L (true value) decreases below 1 as the frequency departs from its fundamental wave. FIG. 2 indicates that the value of $(\omega T/2)$ only should be suppressed to substantially 1 (that is, the sampling period should be set small) when this value (L_m/L) is near twice or three times the

fundamental wave.

Frequency characteristic when the sampling frequency is actually multiplied eight times is indicated by the solid line of FIG. 2. Quantitatively, 5 the relation between an approximate amount ($i_m - i_{m-1}$) of the differential item and a differentiated amount ($v_m + v_{m-1}$) is indicated by the expressions (7) and (8). Therefore, if the sampling frequency is raised (the period is decreased), approximation accuracy of the 10 differential item can be raised.

$$\begin{aligned} \sin(\omega T/2) &= \omega T/2, \cos(\omega T/2) = 1 \\ i_m - i_{m-1} &= 2I \cdot \sin(\omega T/2) \cdot \cos(\omega t_m - \omega T/2) \\ &= 2I \cdot \omega T/2 \cdot \cos(\omega t_m - \omega T/2) \quad \cdots (7) \\ v_m + v_{m-1} &= 2V \cdot \cos(\omega T/2) \cdot \sin(\omega t_m - \omega T/2 + \theta) \\ &= 2V \cdot \sin(\omega t_m - \omega T/2 + \theta) \quad \cdots (8) \end{aligned}$$

However, the value of the expression (7) is a very small value with respect to an amplitude value I. Therefore, a relative value of noise (quantization error generated at the time of A/D conversion, white 20 noise generated in an analog circuit) contained in sampling data (i_m, i_{m-1}) is increased thereby disabling practical use of this method.

For example, when the sampling period T is 25 $T = 1/4800$ sec, $\omega_0 = 2\pi \cdot 50$ Hz, the second item $\varepsilon / (\omega_0 T/2)$ on the right side of the expression (9) is amplified to about 30 times. An ε in the expression (9) is noise error.

$$(i_m - i_{m-1}) / (\omega_0 T/2) \\ = 2I \cdot (\omega / \omega_0) \cdot \cos(\omega t_m - \omega T/2) + \varepsilon / (\omega_0 T/2) \quad \cdots (9)$$

BRIEF SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is
5 to provide an improved protection relay.

A protection relay for determining whether or not
a faultal point of a power system exists in a predeter-
mined range, according to a first aspect of the present
invention is characterized by comprising: filter means
10 for inputting sampling data of a voltage and a current
in the power system to a digital filter having a
predetermined transfer function and outputting a first
voltage data and a first current data, and a second
voltage data and a second current data normal to
15 the first voltage data and the first current data,
respectively; calculation means for calculating
a predetermined measurement value based on the first
voltage data, the first current data, the second
voltage data and the second current data at a first
20 time and the first voltage data, the first current
data, the second voltage data and the second current
data at a second time different from the first time;
and operation decision means for performing
an operation decision based on the predetermined
25 measurement value obtained by the calculation means.

A protection relay for determining whether or
not a faultal point of a power system exists in

a predetermined range, according to a second aspect of the present invention is characterized by comprising: filter means in which sampling data of voltage and current in the power system is inputted to a predetermined transfer function so as to output first voltage data and first current data and second voltage data and second current data normal to the first voltage data and the first current data, respectively; polarized voltage value calculation means for inputting the first and second voltage data and the first and second current data so as to calculate a third voltage normal to the first voltage; and operation decision means for performing an operation decision based on the third voltage.

15 A protection relay for determining whether or not a faultal point of power system exists in a predetermined range, according to a third aspect of the present invention is characterized by comprising: first filter means for inputting sampling data v_m and i_m of voltage v and current i in the power system to a digital filter having transfer function $f(z) \cdot (1+k \cdot z^{-1} + z^{-2})$ (z indicates a Z conversion operator) so as to output voltage data v_{sm} and current data i_{sm} ; second filter means in which the sampling data v_m , i_m are inputted to a digital filter having transfer function $f(z) \cdot (1-z^{-2})$ (z indicates a Z conversion operator) so as to output voltage data v_{jm} and current data i_{jm} normal to the

voltage data v_{sm} and current data i_{sm} ; charging current compensation calculation means for calculating quantity of electricity defined in $i_{sm} - C \cdot v_{jm}$ by the current data i_{sm} , the voltage data v_{jm} , and a setting value 5 C_s at time t_m ; transmission and reception means for transmitting output of the charging current compensation calculation means to an opposite terminal and when quantity of electricity at the opposite terminal is assumed to be B , receiving quantity of 10 electricity defined by $(i_{sm} - C \cdot v_{jm})B$ at the opposite terminal; and operation decision means for performing an operation decision based on outputs from the charging current compensation calculation means and the transmission/reception means according to the 15 following expression:

$$\| (i_{sm} - C_s \cdot v_{jm}) + (i_{sm} - C_s \cdot v_{jm})B \| \geq ka \cdot \{ \| i_{sm} - C_s \cdot v_{jm} \| + \| (i_{sm} - C_s \cdot v_{jm})B \| \} + kb$$

where, $\|am\|$ represents a quantity parallel to amplitude of AC quantity of electricity "a" at time t_m ;

20 ka represents a proportion restricting coefficient; and

kb represents minimum sensitivity current.

Additional objects and advantages of the invention will be set forth in the description which follows, and 25 in part will be obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention may be realized and

obtained by means of the instrumentalities and combinations particularly pointed out hereinafter.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

The accompanying drawings, which are incorporated 5 in and constitute a part of the specification, illustrate embodiments of the invention, and together with the general description given above and the detailed description of the embodiments given below, serve to explain the principles of the invention.

10 FIG. 1 is a power system diagram, which is an object of the present invention;

FIG. 2 is a diagram showing frequency characteristic of a reactance measurement value which is an object of the present invention;

15 FIG. 3 is a diagram showing frequency characteristic of a reactance measurement value in a digital filter structure, which is an object of the present invention;

20 FIG. 4 is a block diagram of a protection relay according to a first embodiment of the present invention;

FIG. 5 is a block diagram of a protection relay according to a first modification of the first embodiment;

25 FIG. 6 is a diagram showing reactance characteristic on an impedance plane;

FIG. 7 is a block diagram of a protection relay

according to a second modification of the first embodiment;

FIG. 8 is a block diagram of a protection relay according to a third modification of the first 5 embodiment;

FIG. 9 is a diagram showing Ohm characteristic on an impedance plane;

FIG. 10 is a block diagram of a protection relay according to a second embodiment of the present 10 invention;

FIG. 11 is a diagram showing offset mho characteristic on an impedance plane;

FIG. 12 is a block diagram of a protection relay according to a third embodiment of the present 15 invention;

FIG. 13 is a diagram showing the relation between maximum sensitive angle of mho characteristic and permanent impedance;

FIG. 14 is a diagram showing mho characteristic 20 expressed with reference to current;

FIG. 15 is a block diagram of a protection relay according to a first modification of the third embodiment;

FIG. 16 is a block diagram of a protection relay 25 according to a second modification of the third embodiment;

FIG. 17 is a block diagram of a protection relay

according to a fourth embodiment of the present invention; and

FIG. 18 is a diagram for explaining a telegraph equation of a power transmission line.

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DETAILED DESCRIPTION OF THE INVENTION

Prior to description of respective embodiments of the present invention, the principle of the present invention will be described. If sampling data of current $i = I \cdot \sin(\omega t)$ is passed through transfer

10 function $f(Z) = (1+Z^{-1}+Z^{-2}+ \dots +Z^{-n})$, current i'_{sm} at time t_m indicated in the expression (10) is obtained.

$$\begin{aligned} i'_{sm} &= I \cdot (\sin(\omega t_m) + \sin(\omega t_m - \omega T) + \dots + \sin(\omega t_m - n\omega T)) \\ &= I \cdot (\sin((n+1)\omega T/2) / \sin(\omega T/2)) \cdot \sin(\omega t_m - n\omega T/2) \\ &\dots (10) \end{aligned}$$

15 If this current i'_{sm} is passed through transfer function $(1+k \cdot Z^{-1}+Z^{-2})$, current i_{sm} at time t_m indicated in the expression (11) is obtained.

$$\begin{aligned} i_{sm} &= i'_{sm} + k \cdot i'_{sm-1} + i'_{sm-2} \\ &= I \cdot (k + 2\cos(\omega T)) \cdot (\sin((n+1)\omega T/2) / \\ &\quad \sin(\omega T/2)) \cdot \sin(\omega t_m - (n+2)\omega T/2) \dots (11) \end{aligned}$$

Likewise, current $i = I \cdot \sin(\omega t)$ is passed through the transfer function $f(Z) \cdot (1-Z^{-2})$, current i_{jm} at time t_m is obtained as indicated in the expression (12).

$$\begin{aligned} i_{jm} &= 2I \cdot \cos(\omega T/2) \sin((n+1)\omega T/2) \cdot \cos(\omega t_m - (n+2)\omega T/2) \\ &\dots (12) \end{aligned}$$

Voltage can be obtained in the same manner as current and if it is assumed that the voltages are v_{sm}

and v_{jm} , they are in such a relation that they are normal to each other.

Thus, if as the fundamental wave, its value which is as near 1 as possible is selected as long as the 5 quantity for determining the size of the right side of the expression (12) is not $|\sin((n+1)\omega T/2)| \ll 1$, performance of frequency characteristic can be assured while suppressing amplification of noise error.

Therefore, if i_{jm} , i_{sm} , and v_{sm} at time t_m and 10 i_{jm-1} , i_{sm-1} , and v_{sm-1} at time t_{m-1} are substituted for:

$$x_m = \frac{-v_{sm} \cdot i_{sm-p} + i_{sm} \cdot v_{sm-p}}{-i_{jm} \cdot i_{sm-p} + i_{jm-p} \cdot i_{sm}} \quad \dots (13)$$

where m and p represent sampling time series, 15 voltage v_{sm} is provided in the form of:

$$v_{sm} = V \cdot (k + 2 \cos(\omega T)) \cdot (\sin((n+1)\omega T/2) / \sin(\omega T/2) \cdot \sin(\omega t_m + \theta - (n+2)\omega T/2)) \quad \dots (14)$$

As a result, a reactance value x_m is indicated in the expression (15):

$$x_m = \frac{V(k + 2 \cos(\omega T))}{I \sin(\omega T)} \cdot \sin(\theta) \quad \dots (15)$$

where θ represents a leading angle of Voltage to current.

Therefore, when n is increased sufficiently in 25 the expression (12), an influence of the noise error can be reduced. Frequency characteristic of x_m relative to the fundamental wave can be indicated in

a graph shown in FIG. 3. From this graph, it is evident that $k = 4$ provides the most excellent frequency characteristic.

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$$X_m/X \text{ (value at fundamental wave)} \\ = \frac{(k + 2 \cos(\omega T)) / (k + 2 \cos(\omega_0 T))}{\sin(\omega T) / \sin(\omega_0 T)} \quad \dots (16)$$

A protection relay according to a first embodiment of the present invention will be described based on the above-described principle with reference to FIG. 4.

10 FIG. 4 is a block diagram showing schematically the structure of the protection relay according to the first embodiment. The protection relay of the first embodiment suppresses amplification of the noise error contained in minute quantity of data even when the

15 sampling period is shortened, in order to secure performance of frequency characteristic indicated in the expression (4).

Referring to FIG. 4, a first (digital) filter 1 comprises a digital filter (Z indicates a Z conversion operator) which outputs sampling data v_m and i_m about voltage v and current i of a power system as voltage data v_{sm} and current data i_{sm} through transfer function $f(Z) \cdot (1+k \cdot Z^{-1} + Z^{-2})$ and extracts predetermined frequency components of voltage and current of a power system

25 (not shown), which is a protecting object.

A second (digital) filter 2 comprises a digital filter (Z indicates a Z conversion operator) which

outputs sampling data v_m and i_m as voltage data v_{jm} and i_{jm} through transfer function $f(Z) \cdot (1-Z^{-2})$ and extracts voltage and current normal to the first filter 1 in all frequency components.

5 A reactance value calculator 3 calculates a reactance value X_m from voltage data v_{sm} , current data i_{sm} , voltage data v_{jm} and voltage data i_{jm} at time t_m and voltage data i_{sm-p} , current data i_{sm-p} , voltage data v_{jm-p} and current data i_{jm-p} at time t_{m-p} .

10 An operation decision section 4 compares the reactance value X_m obtained by the reactance calculator 3 with a preliminarily set integer (whether or not $X_m \leq X_s$ is determined with X_s). The preliminarily set integer value is called setting value in this 15 specification.

With such a configuration, the first filter having the transfer function $f(Z) \cdot (1+k \cdot Z^{-1} + Z^{-2})$ receives input of sampling data v_m and i_m about voltage v and current i of the power system and outputs voltage data v_{sm} and 20 current data i_{sm} .

Further, the second filter having the transfer function $f(Z) \cdot (1-Z^{-2})$ receives input of sampling data v_m and i_m about the voltage v and current i and outputs voltage data v_{jm} and current data i_{jm} .

25 The reactance value calculator 3 calculates a reactance value X_m from the voltage data v_{sm} and current data i_{sm} obtained by the first filter 1 and

voltage data v_{jm} and current data i_{jm} obtained by the second filter 2 at time t_m , and voltage data v_{sm-p} and current data i_{sm-p} obtained by the first filter 1 and voltage data v_{jm-p} and current data i_{jm-p} obtained by the second filter 2 at time t_{m-p} according to the expression (17):

$$x_m = \frac{-v_{sm} \cdot i_{sm-p} + i_{sm} \cdot v_{sm-p}}{-i_{jm} \cdot i_{sm-p} + i_{jm-p} \cdot i_{sm}} \cdots (17)$$

where, m and p represent sampling time series.

Further, the operation decision section 4 decides whether or not $x_m \leq x_s$ is established from the reactance value x_m and setting value x_s obtained by the reactance value calculator 3 and when that relation is established, it decides it is active and otherwise, it decides it is inactive.

The transfer functions of the first and second filters 1 and 2 are expressed in $f(z) \cdot (1+k \cdot z^{-1} + z^{-2})$ and $f(z) \cdot (1-z^{-2})$ when the Z conversion operator is employed. As already described before, the outputs of the first and second filters 1 and 2 are normal to each other. There is a relation that the output of the first filter 1 is delayed at 90° with respect to the output of the second filter 2.

It is permissible to define these transfer functions with transfer function 1: $f(z)$, transfer function 2: $(1+k \cdot z^{-1} + z^{-2})$ and transfer

function 3: $1-z^{-2}$ and form the first filter 1 and the second filter 2 by combining those.

That is, the same output can be obtained by passing the input voltage and current through a digital 5 filter of the transfer function 1 and then passing its output through digital filters of the transfer functions 2 and 3.

The reactance value calculator 3 of FIG. 4 calculates a reactance value from a protection relay 10 installation point in a power transmission line of FIG. 1 up to a faultal point according to the expression (17). Assuming that the input voltage and current are $i = I \cdot \sin(\omega t)$, and $v = V \cdot \sin(\omega t + \theta)$, the expression (17) can be expressed in the 15 expression (15).

The operation decision section 4 corrects the decision expression using the reactance value X_m , setting value X_s and preliminarily set fundamental wave constant $\sin(\omega_0 T) / (k+2 \cdot \cos(\omega_0 T))$ with respect to the 20 reactance value X_m calculated by the reactance value calculator 3 as indicated in the expression (18) so as to decide whether or not it is active. Such operation decision is carried out plural times ordinarily.

$$X_m \leq X_s / (\sin(\omega_0 \cdot T) / (k+2 \cdot \cos(\omega_0 \cdot T))) \quad \cdots (18)$$

Consequently, amplification of error due to 25 approximation of the differential item is suppressed, so that L_m / L (true value) becomes a characteristic

which is as near 1 as possible in a wide frequency band. Therefore, it is possible to block an influence even when a harmonic component occurs in fault voltage and fault current of the power system thereby improving 5 reliability.

According to the above description, the reactance value calculator 3 calculates the reactance value using outputs of the first filter 1 and the second filter 2 and the operation decision section 4 decides whether or 10 not it is active according to the condition expression (18) based on that reactance value.

The present invention is not restricted to this example, but it is permissible for an operating restraint quantity calculator 5 to calculate a_m and b_m 15 according to the expression (19) based on the outputs of the first filter 1 and the second filter 2 and then for an operation decision section 6 to decide the operation according to the expression (20) to be described later using that result.

$$20 \quad a_m = -v_{sm} \cdot i_{sm} - p + v_{sm} - p \cdot i_{sm}$$
$$b_m = -i_{jm} \cdot i_{sm} - p + i_{jm} - p \cdot i_{sm} \quad \cdots (19)$$

That is, when current $i = I \cdot \sin(\omega t)$ and voltage $v = V \cdot \sin(\omega t + \theta)$ are inputted to the first filter 1 of the transfer function $f(Z) \cdot (1 - k \cdot Z^{-1} + Z^{-2})$ and the second 25 filter 2 of the transfer function $f(Z) \cdot (1 - Z^{-2})$, the expression (19) is converted to the expression (20), providing that $f(Z) = (1 + Z^{-1} + Z^{-2} + \cdots + Z^{-n})$.

$$\begin{aligned} a_m &= IV \{ (k+2\cos(\omega T))^2 \cdot \\ &\quad (\sin((n+1)\omega T/2)/\sin(\omega T/2))^2 \} \cdot \sin(\theta) \cdot \sin(p\omega T) \\ b_m &= 2I^2 \{ \cos(\omega T/2) \cdot \sin((n+1)\omega T/2) \cdot \\ &\quad (k+2\cos(\omega T)) \cdot (\sin((n+1)\omega T/2)/\sin(\omega T/2)) \} \\ &\quad \cdot \sin(p\omega T) \end{aligned} \quad \cdots (20)$$

The operation decision section 6 corrects sensitivity constant K_0 and reactance setting value X_S to $X_S \leftarrow X_S / (\sin(\omega_0 T) / (k+2 \cdot \cos(\omega_0 T)))$ using a_m and b_m outputted in this way and decides the operation 10 according to a decision expression of the expression (21).

$$b_m \cdot X_m - a_m \geq k_0 \quad \cdots (21)$$

Although this is a different method from the above-described method, it has the reactance 15 characteristic as shown in FIG. 6 like that example.

Consequently, amplification of error due to approximation of the differential item is suppressed, so that L_m/L (true value) becomes a characteristic which is as near 1 as possible in a wide frequency 20 band. Therefore, it is possible to block an influence even when a harmonic component occurs in fault voltage and fault current of the power system thereby improving reliability.

Further, it is permissible to use an Ohm value 25 calculator 7 defined by expression (22) as shown in FIG. 7 as such calculation means or an operation decision section 8 defined by the expression (25),

which will be described later.

$$R_m = \frac{-i_{jm} \cdot v_{sm-p} + v_{sm} \cdot i_{jm-p}}{-i_{jm} \cdot i_{sm-p} + i_{jm-p} \cdot i_{sm}} \quad \dots (22)$$

With this configuration, when current

5 $i = I \cdot \sin(\omega t)$ and voltage $v = V \cdot \sin(\omega t + \theta)$ are inputted into the first filter 1 of the transfer function $f(z) \cdot (1+k \cdot z^{-1} + z^{-2})$ and the second filter 2 of the transfer function $f(z) \cdot (1-z^{-2})$, the expression (23) is established, providing that $f(z) = (1+z^{-1}+z^{-2}+ \dots +z^{-n})$. Further, the Ohm value R_m is converted to the expression (24) because of the relation of the expression (20).

10

$$\begin{aligned} & -i_{im} \cdot v_{sm-p} + i_{jm-p} \cdot v_{sm} \\ & = 2IV \cos(\omega T/2) \cdot \sin((n+1)\omega T/2) \cdot (k+2\cos(\omega T)) \cdot \\ & 15 \quad (\sin((n+1)\omega T/2)/\sin(\omega T/2)) \cdot \cos(\theta) \cdot \sin(p\omega T) \end{aligned} \quad \dots (23)$$

$$R_m = (V/I) \cdot \cos(\theta) \quad \dots (24)$$

The operation decision section 8 decides whether or not a decision expression for the expression (25) is established based on the Ohm value R_m and the setting value R_s calculated from the expression (24) and when that expression is established, it decides it is active.

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$$R_m \leq R_s \quad \dots (25)$$

25 Consequently, amplification of error due to approximation of the differential item is suppressed, so that L_m/L (true value) becomes a characteristic

which is as near 1 as possible in a wide frequency band. Therefore, it is possible to block an influence even when a harmonic component occurs in fault voltage and fault current of the power system thereby improving
5 reliability.

Further, it is permissible to use an operation restricting quantity calculator 9 defined by the expression (26) shown in FIG. 8 or an operation decision section 10 defined by the expression (28)
10 which will be described later, as such calculation means.

$$\begin{aligned} c_m &= -i_{jm} \cdot v_{sm-p} + v_{sm} \cdot i_{jm-p} \\ b_m &= -i_{jm} \cdot i_{sm-p} + i_{jm-p} \cdot i_{sm} \end{aligned} \quad \dots (26)$$

That is, when current $i = I \cdot \sin(\omega t)$ and voltage
15 $v = V \cdot \sin(\omega t + \theta)$ are inputted to the first filter 1 of the transfer function $f(z) \cdot (1 - k \cdot z^{-1} + z^{-2})$ and the second filter 2 of the transfer function $f(z) \cdot (1 - z^{-2})$, the expression (26) is converted to the expression (27), providing that $f(z) = (1 + z^{-1} + z^{-2} + \dots + z^{-n})$.

$$\begin{aligned} 20 \quad m &= -i_{jm} \cdot v_{sm-p} + i_{jm-p} \cdot v_{sm} \\ &= 2IV \cos(\omega T/2) \cdot \sin((n+1)\omega T/2) \cdot (k + 2\cos(\omega T)) \cdot \\ &\quad (\sin((n+1)\omega T/2) / \sin(\omega T/2)) \cdot \cos(\theta) \cdot \sin(p\omega T) \end{aligned} \quad \dots (27)$$

Then, the operation decision section 10 decides
25 whether or not it is active based on the decision expression (28) from c_m , b_m , Ohm setting value R_s and sensitivity constant K_1 .

$$R_S - C_M \geq k_1 \quad \dots (28)$$

Such protection relay has Ohm characteristic shown in FIG. 9 like the configuration described with reference to FIG. 7 before and is different from it 5 only in its realization method.

Consequently, amplification of error due to approximation of the differential item is suppressed, so that L_M/L (true value) becomes a characteristic which is as near 1 as possible in a wide frequency 10 band. Therefore, it is possible to block an influence even when a harmonic component occurs in fault voltage and fault current of the power system thereby improving reliability.

Next, a second embodiment of the present invention 15 will be described with reference to the accompanying drawings. A description of the same configuration as the above-described embodiment is omitted appropriately while like reference numerals are attached to the same components in the Figures.

According to the first embodiment, for example, FIG. 4 indicates calculation of reactance and FIGS. 5, 20 8 indicate calculation of operating restraint quantity, and FIG. 7 indicates calculation of Ohm value and decision of operation based thereon.

This embodiment contains the Ohm value calculator 25 7 and reactance value calculator 3 as shown in FIG. 10 and then, the operation decision section 11 decides

the operation using these outputs.

That is, the voltage v_{sm} , current i_{sm} and voltage
5 v_{jm} , current i_{jm} outputted from the first filter 1 and
the second filter 2 are inputted to the Ohm value
calculator 7 for calculating Ohm value and the
reactance value calculator 3 for calculating reactance.
The Ohm value calculator 7 calculates an Ohm value R_m
according to the expression:

10
$$R_m = \frac{-i_{jm} \cdot v_{sm-p} + v_{sm} \cdot i_{jm-p}}{-i_{jm} \cdot i_{sm-p} + i_{jm-p} \cdot i_{sm}}$$

The reactance value calculator 3 calculates
reactance X_m according to the expression (13).

15 The operation decision section 11 decides whether
or not it is active according to the expression (29)
using the Ohm value R_m and the reactance value X_m .
This protection relay has offset mho characteristic
indicated in FIG. 11:

$$(R_m - R_0) \cdot (R_m - R_p) + (X_m - X_0) \cdot (X_m - X_F) \leq 0 \quad \cdots (29)$$

where, R_0 (Ohm component) represents an offset mho near
20 side setting value;

X_0 (reactance component) represents an offset
mho near side setting value;

R_F (Ohm component) represents an offset mho far
side setting value; and

25 X_F (reactance component) represents an offset
mho far side setting value.

A third embodiment of the present invention will

be described with reference to the accompanying drawings. Description of the same configuration as the above-described embodiments is omitted while like reference numerals are attached thereto.

5 A protection relay of this embodiment comprises a polarized voltage value calculator 12 in which voltage v_{sm} , current i_{sm} and voltage v_{jm} , current i_{jm} are inputted in order to extract voltage v_{pim} normal to voltage v_{sm} and an operation decision section 13 in
10 which the aforementioned voltages and currents are inputted while voltage v_{pim} is inputted from the polarized voltage value calculator 12 so as to decide whether or not it is active according to the expression (30).

15 $v_{pjm-p} \cdot ((R_s \cdot i_{sm} + X_s \cdot i_{jm}) - v_{sm}) - v_{pjm} \cdot ((R_s \cdot i_{sm-p} + X_s \cdot i_{jm-p}) - v_{sm-p}) \geq K2 \quad \dots (30)$

20 In the meantime, R_s and X_s are setting value s of an Ohm component and a reactance component respectively, while X_s is corrected in the form of $X_s \leftarrow X_s / (\sin(\omega_0 T) / (k+2 \cdot \cos(\omega_0 T)))$.

25 In the expression (30), the quantities of electricity in the item of $(R_s \cdot i_{sm} + X_s \cdot i_{jm})$ and item of $(R_s \cdot i_{sm-p} + X_s \cdot i_{jm-p})$ are in such a relation that they are advanced only in size of $(R_s^2 + X_s^2)^{1/2}$ and phase of $\phi = \tan^{-1}(X_s/R_s)$ with respect to current i_{sm} . Its example will be shown in FIG. 13.

If current $i = I \cdot \sin(\omega t)$ and voltage

$v = V \cdot \sin(\omega t + \theta)$ are inputted to the first filter 1 of the transfer function $f(z) \cdot (1 - k \cdot z^{-1} + z^{-2})$ and the second filter 2 of the transfer function $f(z) \cdot (1 - z^{-2})$, the expression (31) is established, providing that

5 $f(z) = (1 + z^{-1} + z^{-2} + \dots + z^{-n})$:

$$V_{pj} \cdot \{R_s \cdot I_s \cdot \cos(\theta) + X_s / (\sin(\omega_0 T) / (k + 2 \cos(\omega_0 T))) \cdot I_j \cdot \sin(\theta) - V_s\} \cdot \sin(p \omega T) \geq K2$$

where: $I_s = I(k + 2 \cos(\omega T)) (\sin((n+1) \omega T / 2) / \sin(\omega T / 2))$

$$V_s = V(k + 2 \cos(\omega T)) (\sin((n+1) \omega T / 2) / \sin(\omega T / 2))$$

10 $I_j = 2I \cos(\omega T / 2) \sin((n+1) \omega T / 2) \dots (31)$

Then, if the expression (31) is expressed with Z_s (size: $(R_s^2 + X_s^2)^{1/2}$ and phase $\phi = \tan^{-1}(X_s / R_s)$, expression (32) is established. Therefore, the expression (32) indicates operation principle

15 expression of mho characteristic shown in FIG. 14 if its frequency is basic frequency.

$$V_{pj} \cdot \{Z_s \cdot I_s \cdot \cos(\theta) \cos(\phi) + Z_s \cdot I_j \cdot \sin(\theta) \sin(\phi) / (\sin(\omega_0 T) / (k + 2 \cos(\omega_0 T)) - V_s) \cdot \sin(p \omega T)\}$$

$$= V_{pj} \cdot \{Z_s \cdot I \cdot (\cos(\theta) \cos(\phi) (k + 2 \cos(\omega T)) /$$

20 $\sin(\omega T) + \sin(\theta) \sin(\phi)$

$$(k + 2 \cos(\omega_0 T)) / \sin((\omega_0 T)) - V_s\} \cdot \sin(p \omega T)$$

$\therefore \omega = \omega_0$

$$= V_{pj} \cdot \{Z_s \cdot I \cdot \cos(\theta - \phi) - V_s\} \cdot \sin(p \omega T) \geq K2 \dots (32)$$

The above-described structure indicates a case where voltage v_{pj_m} normal to voltage v_{sm} in the fundamental wave is extracted by the polarized voltage value calculator 12. The present invention is not

restricted to this example. For example, it is permissible to provide with a polarized voltage value calculator 14 which regards a voltage before predetermined cycles (data before N samplings) of the voltage v_{jm} normal to voltage v_{sm} as polarized voltage as shown in FIG. 15. In this case, the voltage v_{pj_m} and voltage v_{sm} are indicated in the expression (33).

$$\begin{aligned} v_{pj_m} &= 2V \cdot \sin((n+1)\omega T/2) \cdot \cos(\omega T/2) \\ &\quad \cdot \cos(\omega t_m + \theta = N\omega T - (n+2)\omega T/2) \\ 10 \quad v_{sm} &= V \cdot (k + 2\cos(\omega T)) \cdot \sin((n+1)\omega T/2) / \\ &\quad \sin(\omega T/2) \cdot \sin(\omega t_m + \theta - (n+2)\omega T/2) \quad \cdots (33) \\ &\quad (N\omega_0 T = 2\pi \cdot M, M \text{ is an integer}) \end{aligned}$$

It is permissible to provide with a polarized voltage value calculator 15 for extracting voltage v_{pim} normal to voltage v_{sm} as shown in FIG. 16 and if this is for detecting a short-circuit, in case of, for example, AB phase, extract positive sequence voltage relative to the AB phase. A, B, and C indicate each phase of three-phase AC quantity of electricity.

For example, positive sequence voltage relative to the AB phase can be extracted according to $v_{psm}(AB) = -3^{1/2} (v_{jm}(C) - v_{jm}(0)) + v_{sm}(AB)$. Here, $v_{sm}(0)$ indicates zero phase quantity of electricity.

Further, if this is for ground fault, the positive sequence voltage relative to A phase can be calculated according to $v_{psm}(A) = 3^{1/2} \cdot (v_{sm}(A) - v_{sm}(0) + v_{jm}(BC))$.

In addition to the method for extracting voltage

vector from two electricity quantities normal to each other, it is permissible to apply a method in which sampling time series is shifted by 90° or equivalent.

Consequently, amplification of error due to
5 approximation of the differential item is suppressed, so that L_m/L (true value) becomes a characteristic which is as near 1 as possible in a wide frequency band. Therefore, it is possible to block an influence even when a harmonic component occurs in fault voltage
10 and fault current of power system thereby improving reliability.

A fourth embodiment of the present invention will be described with reference to FIG. 17. Description of the same configuration as the above-described
15 embodiments is omitted while like reference numerals are attached thereto.

FIG. 17 is a block diagram of a protection relay applied to description of this embodiment. According to the fourth embodiment, outputs from the first filter 1 and the second filter 2 are inputted to a charging current compensation calculator 16 and its output is inputted to an operation decision section 18 which follows operation decision principle of ratio differential relay type so as to decide whether or not
25 it is active.

The charging current compensation calculator 16 corrects a setting value C_s in the form of

$C_s \leftarrow C_s \cdot (k + 2\cos(\omega_0 T) / \sin(\omega_0 T))$ and calculates $i_{sm} - C_s \cdot v_{jm}$ using output current i_{sm} from the first filter 1 and output voltage v_{jm} from the second filter 2. In the meantime, $C_s \cdot v_{jm}$ indicates current compensation generated by charge capacity C_s .

Then, opposing quantity of electricity $(i_{sm} - C_s \cdot v_{jm})B$ of an opposite terminal is received by transmission and reception section 17 and quantity of electricity of itself terminal is transmitted to the electric power station. Here, B indicates quantity of electricity at an opposite terminal.

After that, the operation decision section 18 decides the operation based on vectorial sum of current which compensates for charge current at itself terminal obtained by the charging current compensation calculator 16 and current which compensates for charge current at a terminal of the opposite terminal, namely, scalar sum of amplitude value of differential current and currents which compensate for charge current at each terminal, according to expression (34):

$$\| (i_{sm} - C_s \cdot v_{jm}) + (i_{sm} - C_s \cdot v_{jm})B \| \geq ka \cdot \{ \| (i_{sm} - C_s \cdot v_{jm}) \| + \| (i_{sm} - C_s \cdot v_{jm})B \| \} + kb \quad \dots (34)$$

where, $\|am\|$ represents quantity parallel to amplitude of AC quantity of electricity at time t_m ;

ka represents a proportion restricting coefficient; and

kb represents minimum sensitivity current.

Physical meaning of the charging current compensation indicated in the expression (34) will be described with reference to a power transmission line in FIG. 18. A well known telegraph equation is expressed at transmission/reception terminal as shown in expression (35). Then, if Taylor expansion approximation is executed on differential current $i_{DD}(t)$ with the condition of ($\tau \approx 0$), the expression (36) is obtained:

Waveform of forward movement:

$$i_{DF}(t) = i_s(t - \tau) + e_s(t - \tau)/z + i_R(t + \tau) - e_R(t + \tau)/z$$

Waveform of backward movement:

$$i_{DB}(t) = i_s(t - \tau) - e_s(t - \tau)/z + i_R(t + \tau) + e_R(t + \tau)/z$$

15 Differential current: $i_{DD}(t) = (i_{DF}(t) + i_{DB}(t))/2 \dots (35)$

where, suffix S represents a transmitting terminal;

R represents a receiving terminal;

Z represents a surge impedance =; and

τ represents propagation time = $1/v$ (LC).

20

$$i_{DD}(t) = i_s(t) - (\tau/z) \frac{de_s(t)}{dt} + (\tau^2/z) \frac{d^2e_s(t)}{dt^2} - (\tau^3/3!z) \frac{d^3e_s(t)}{dt^3} \dots$$
$$+ i_R(t) - (\tau/z) \frac{de_R(t)}{dt} + (\tau^2/z) \frac{d^2e_R(t)}{dt^2} - (\tau^3/3!z) \frac{d^3e_R(t)}{dt^3} \dots (36)$$

$\therefore \tau/z = \Sigma C/2$ (1/2 charge capacity in entire SR interval)

25 Even if differential current is extracted with only current vectorial sum current ($i_s(t) + i_R(t)$) at the transmission/reception terminal, the aforementioned

charge current component becomes error current, thereby inducing a drop of sensitivity of the differential relay. Thus, only a fault current component can be extracted by compensating for this.

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$$i_{DD}(t) = i_S(t) - (\tau / z) \frac{de_S(t)}{dt} + i_R(t) - (\tau / z) \frac{de_R(t)}{dt} \quad \dots (37)$$

In the above description, the transfer function $f(z)$ in the first filter 1 and the second filter 2 has been described in the form of
10 $f(z) = (1+z^{-1}+z^{-2}+ \dots +z^{-n})$. It is evident that the same effect can be obtained even if the transfer function is $f(z) = (1+z^{-2}+z^{-4}+ \dots +z^{-2n})$.

In this case, in the expression (10), $\omega T/2$ only should be replaced for ωT and in that case, the expression (38) is established. Likewise, the expressions (8) and (12) only should be replaced. For convenience of following description, it is described that $f_1 = f(z) = (1+z^{-1}+z^{-2}+ \dots +z^{-n})$, and $f_2 = f(z) = (1+z^{-2}+z^{-4}+ \dots +z^{-2n})$.

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$$\begin{aligned} i'_{sm} &= I \cdot (\sin(\omega t_m) + \sin(\omega t_m - 2\omega T) + \dots + \sin(\omega t_m - 2n\omega T)) \\ &= I \cdot (\sin((n+1)\omega T) / \sin(\omega T)) \cdot \sin(\omega t_m - n\omega T) \quad \dots (38) \end{aligned}$$

If f_1 is replaced to f_2 , the quantity of data in the latter can be reduced assuming that the window length of data for use is the same and approximation error of integration is of the same value. For example, if $n = 2$ is adapted in case of f_1 , $n = 1$ may be adapted in case of f_2 .

Because gain in the first filter 1 and the second filter 2 using f_1 is larger than gain in the first filter 1 and the second filter 2 using f_2 , noise error can be compressed by that amount.

5 For example, when f_1 is used, gain G_1 of $n = 2$ is expressed in the expression (39) and if f_2 is used, gain G_2 of $n = 2$ is expressed in the expression (40).

$$G_1 = |\sin(3\omega T/2)/\sin(\omega T/2)| = |2\cos(\omega T)+1| \quad \cdots (39)$$

$$G_2 = |\sin(2\omega T)/\sin(\omega T)| = |2\cos(\omega T)| \quad \cdots (40)$$

10 Such transfer function $f(Z)$ is constructed with FIR filter. The present invention is not restricted to this example, but the same integration error characteristic can be achieved even when it is constructed with recursive digital filter.

15 Consequently, amplification of error due to approximation of the differential item is suppressed, so that L_m/L (true value) becomes a characteristic which is as near 1 as possible in a wide frequency band. Therefore, it is possible to block an influence 20 even when a harmonic component occurs in fault voltage and fault current of the power system thereby improving reliability.

According to the present invention, as described above, even when a harmonic component is overlaid on 25 a fault current and a fault voltage generated upon a fault of a power system, a predetermined time differential equation can be solved approximately by

passing through predetermined digital filters normal to each other in a wide frequency band, thereby achieving a high accuracy protection relay.

Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details and representative embodiments shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.

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